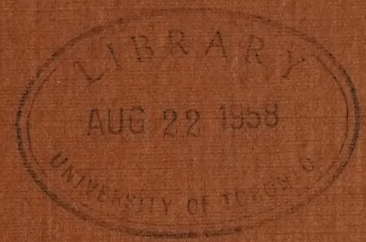


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COPY FOR MR. J. ALLAN ROSS



HYDRO-ELECTRIC INQUIRY COMMISSION

ENGINEERING DATA

THE ONTARIO POWER COMPANY OF NIAGARA FALLS

REPORT

ON

ACCIDENT ON APRIL 20th, 1922

WALTER J. FRANCIS, C. E.

CONSULTING ENGINEER

POWER COMMISSION ACT

Salary of 5 - (1) The Chairman of the Commission shall be paid
Chairman an annual salary of \$6,000. per annum and the same shall be a charge upon and payable out of the Consolidated Revenue Fund of Ontario.

Remuneration of Commissioners (2) The Chairman and each of the other members of the Commission may be paid such annual sum for their services as members of the Commission as may be determined by the Lieutenant-Governor in Council out of moneys to be provided as set out in clause c to section 23 of this Act.

Seat of member of Assembly not vacated or penalties incurred by becoming a member of Commission (3) Notwithstanding anything contained in The Legislative Assembly Act the election of the Chairman or any other member of the Commission if a member of the Assembly shall not by reason of the payment to him of any salary or other remuneration under this Act, or the acceptance thereof be avoided, nor shall he vacate or forfeit his seat or incur any of the penalties imposed by that Act for sitting and voting as a member of the Assembly. 6 Geo.V.C.19 s.2 part

(Note: Subsections 2 and 3 (above) were made retroactive from November 1st, 1914, and apply to the services of any member of the Commission since that date 5 Geo.V.C.19 s.2)

POWER COMMISSION ACT

Salary of 5 - (1) The Chairman of the Commission shall be paid an annual salary of \$5,000. per annum and shall be a charge upon and payable out of the Consolidated Revenue Fund of Ontario.

(2) The Chairman and each of the other members of the Commission may be paid such annual and special salaries as may be determined by the Lieutenant Governor in Council out of moneys so provided as set out in clause 3, so provided as set out in clause 3.

Seat of member (3) Notwithstanding anything contained in the Act or otherwise, any member of the Commission shall be deemed to be a member of the Commission for the purpose of the Act, if he is a member of the Assembly and is not a member of the Executive Council and is not a member of the Legislative Assembly and the election of the Chairman or any other member of the Commission by becoming a member of the Commission.

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(4) Notwithstanding anything contained in the Act or otherwise, any member of the Commission shall be deemed to be a member of the Commission for the purpose of the Act, if he is a member of the Assembly and is not a member of the Executive Council and is not a member of the Legislative Assembly and the election of the Chairman or any other member of the Commission by becoming a member of the Commission.

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(Note: Subsections 2 and 3 (above) were made retroactive from November 1st, 1914, and apply to the services of any member of the Commission since that date 5 Geo.V.c.19 s.2)

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shall be deemed a

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remuneration under this Act, or the acceptance

thereof be avoided, nor shall he receive or

forfeit his seat or incur any of the penalties

imposed by that Act for sitting and voting as


a member of the Assembly. 6 Geo.V. c. 19 s. 2

(Note: Sections 2 and 3 above were made

retrospective from November 1st, 1916, and apply

to the services of any member of the Commission

since that date 6 Geo.V. c. 19 s. 2)



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1981

1. The first step in the process of developing a new product is to identify a market need.
2. The second step is to conduct a feasibility study to determine if the product can be developed.
3. The third step is to develop a business plan that outlines the financial aspects of the product.
4. The fourth step is to secure financing for the development of the product.
5. The fifth step is to develop a prototype of the product.
6. The sixth step is to conduct a pilot test of the product.
7. The seventh step is to develop a marketing plan for the product.
8. The eighth step is to launch the product into the market.
9. The ninth step is to monitor the product's performance in the market.
10. The tenth step is to make any necessary adjustments to the product or marketing plan.
11. The eleventh step is to evaluate the overall success of the product development process.
12. The twelfth step is to identify any lessons learned from the process.
13. The thirteenth step is to use the lessons learned to improve future product development efforts.
14. The fourteenth step is to continue to monitor the product's performance in the market.
15. The fifteenth step is to make any necessary adjustments to the product or marketing plan.
16. The sixteenth step is to evaluate the overall success of the product development process.
17. The seventeenth step is to identify any lessons learned from the process.
18. The eighteenth step is to use the lessons learned to improve future product development efforts.
19. The nineteenth step is to continue to monitor the product's performance in the market.
20. The twentieth step is to make any necessary adjustments to the product or marketing plan.

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THE ONTARIO POWER COMPANY OF NIAGARA FALLS

REPORT ON ACCIDENT ON APRIL 20th, 1922.

Walter J. Francis.

Preamble.

At 2:44 o'clock on the morning of April 20th, 1922, while the plant of The Ontario Power Company of Niagara Falls was in operation, an accident occurred which resulted in the demolition of the roof of the northerly part of the plant, the total destruction of one 18,000 horse-power generator and very serious damage to another, with considerable injury to the auxiliary plant connected therewith, and the disablement of four other large generators through water damage. One employee of the Operating Department of the plant was injured, but there were no fatalities. The monetary loss resulting from the accident was very great, probably something on the order of half a million dollars, a figure I mention not as an estimate but as a general indication of the measure of the physical effect of the accident, apart from contingent items.

The present report is made following the instructions given me by the Hydro-Electric Inquiry Commission to study the whole question and ascertain if possible the cause of the accident. In pursuing the study I have conferred freely with all the engineers and officials interested, and as far as possible with all others directly concerned, and I have received the hearty co-operation of all. I should record particularly the unstinted assistance of Mr. F. A.

REPORT OF THE
COMMISSIONER OF THE
BUREAU OF THE CENSUS

1910

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The following is a summary of the results of the investigation conducted by the Bureau of the Census in connection with the fire at the Hotel New York, New York, on the night of January 1, 1910. The fire broke out in the kitchen of the hotel, and spread rapidly to the other parts of the building. The cause of the fire was found to be a gas stove which had been left burning unattended. The fire caused the death of one person and the injury of several others. The property loss was estimated at \$1,000,000. The fire was the result of carelessness on the part of the hotel management. The fire was prevented by the fire department, who arrived at the hotel within five minutes of the time the fire broke out. The fire was extinguished by the fire department, and the fire was prevented from spreading to the other parts of the building. The fire was the result of carelessness on the part of the hotel management. The fire was prevented by the fire department, who arrived at the hotel within five minutes of the time the fire broke out. The fire was extinguished by the fire department, and the fire was prevented from spreading to the other parts of the building.

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Gaby, M.E.I.C., Chief Engineer of the Hydro-Electric Power Commission; of Mr. G. O. Philp, A.M.E.I.C., Superintendent of The Ontario Power Company; and of Mr. W. P. Dobson, A.M.E.I.C., the Engineer in Charge of the laboratories of the Hydro-Electric Power Commission.

I have endeavoured to state all the relevant facts with sufficient accuracy and in enough detail for a general understanding of the subject.

General Description of the Plant.

The Original Plant.

COPY

The original plant as designed by Messrs. P. H. and L. L. Hunn consisted of fourteen main units, numbered consecutively from 1 to 14, the turbine rating of Nos. 1 to 7 being 11,800 horse-power, Nos. 8 to 12, 15,000 horse-power, Nos. 13 and 14, 16,000 horse-power each. All of these units are of the horizontal shaft type, and the turbine head is about 180 feet. The generators are set with the shafts in the same horizontal plane about five feet above the power house floor, and the centre of the rotor of every generator is placed in the same straight line from end to end of the plant.

The power house as originally laid out was built by successive stages, the first part having been put into commission in 1905, and the final additions in October, 1919.

The plant became the property of the Hydro-Electric Power Commission of Ontario in 1917, and has since been operated by that body through its Operating

Department, of which Mr. H. C. Don Carlos is Engineer, reporting directly to Mr. Gaby.

The drawing entitled "Plan of Power House Floor", being page 4 hereof, shows the general plan of the whole floor of the building as at April 22nd, 1922, and, on a larger scale, that part of the floor including Units Nos. 11 to 16 inclusive.

The Hydro-Electric Power Commission Addition.

During the years 1916 and 1919 the Hydro-Electric Power Commission of Ontario made the latest important addition to the plant, consisting of the installation of two complete units in a building which was a continuation of the original building in a northerly direction, the original northerly wall forming a dividing wall between the older part of the plant and the new. The two new units were designated No. 15 and No. 16, continuing the nomenclature of the original plant so that machine No. 15 was adjacent to the dividing wall, No. 16 occupying the more northerly position. Each of the two new units had a turbine rating of 18,000 horse-power, and was generally similar in type and design to the original units. Both generators were set as before with the rotor in the same line as all the others.

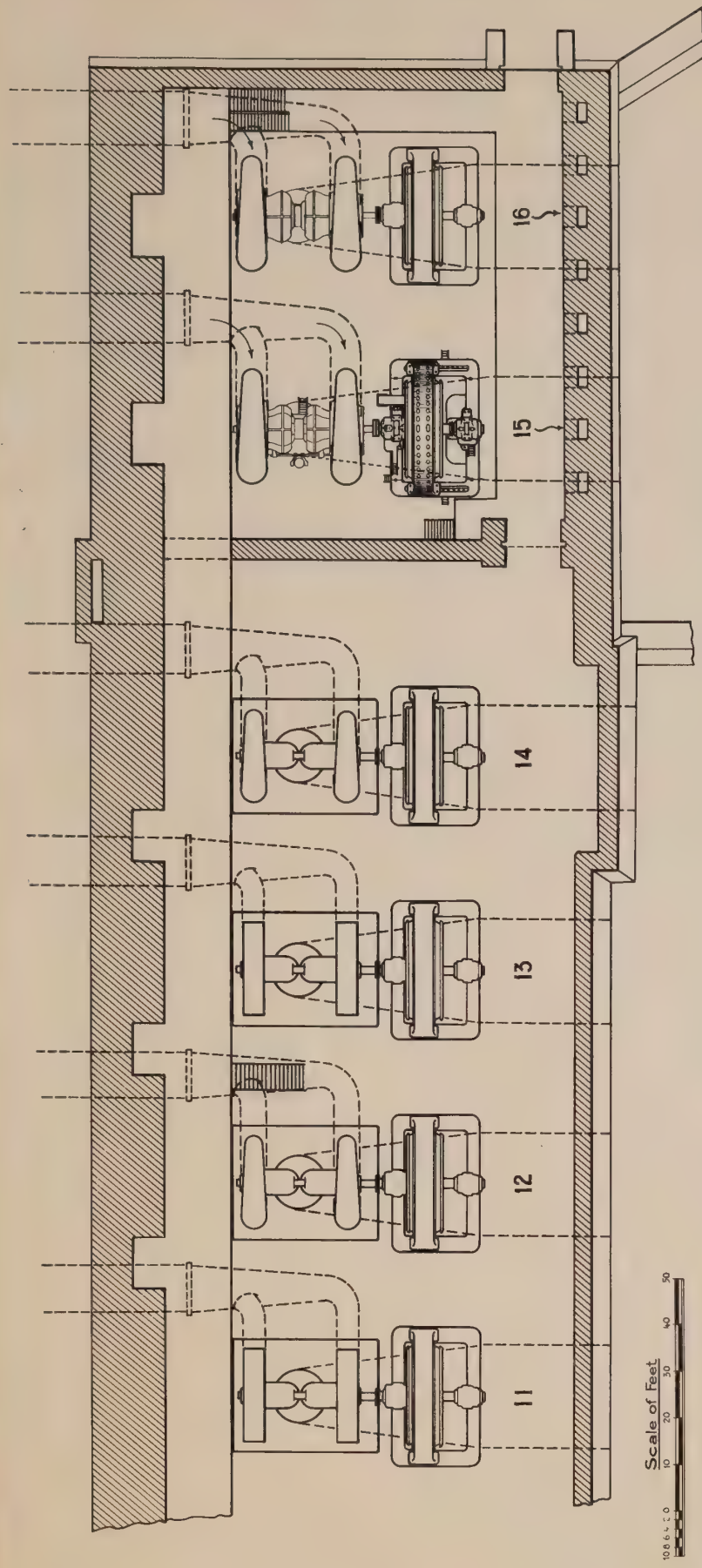
The substructure and the walls of the addition were of concrete, and the floors and galleries were of reinforced concrete. The roof slab was likewise of reinforced concrete, and was supported by steel truss girders.

Unit No. 15 and Unit No. 16 were of the same capacity and were identical

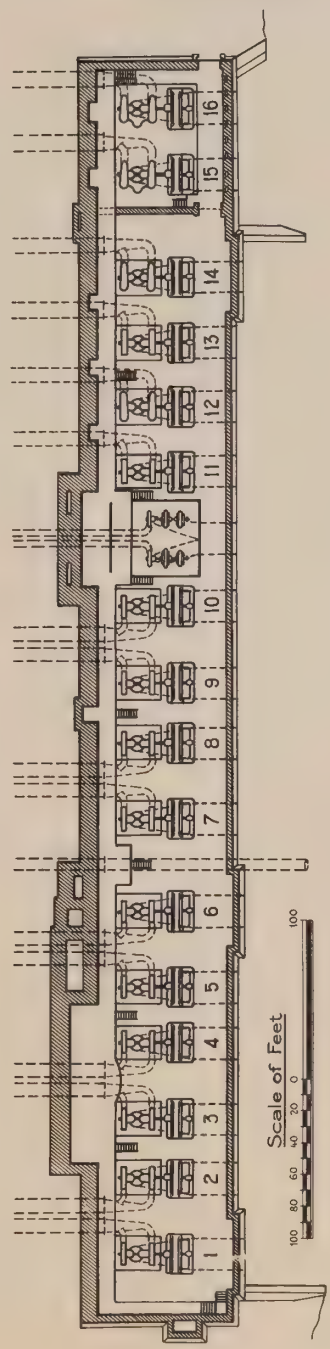
Sheet 1

HYDRO-ELECTRIC INQUIRY COMMISSION
W. D. GREGORY - CHAIRMAN
THE ONTARIO POWER COMPANY OF NIAGARA FALLS
PLAN OF POWER HOUSE FLOOR
Scales as Noted

Toronto, Nov. 18TH, 1922, Made by W.H.A. Checked by *W.H.A.*
WALTER J. FRANCIS, C.E.,
CONSULTING ENGINEER



PLAN OF POWER HOUSE FLOOR SHOWING GENERATORS 11 TO 16



GENERAL PLAN OF POWER HOUSE FLOOR

in detail. The turbines and the generators were manufactured by the same firms, part by part. The turbine of each unit is a horizontal-shaft, double spiral casing, Francis turbine, and the generator of each unit is an alternating current generator of 15,000 kilo-volt ampere capacity at 75% power factor and at 12,000 volts.

The specifications for the generators provided for all the usual conditions, "as known to the present state of the art". The normal speed is specified as 187 $\frac{1}{2}$ revolutions per minute, and Section XIII of the Specification, entitled "Overspeed", reads as follows:- "The generator shall be designed and constructed for and shall withstand an overspeed test of 360 revolutions per minute without injury, excessive vibration or failure".

Article XXIII - General Guarantee, reads as follows:- "The Contractor hereby guarantees that the generators furnished hereunder will conform in all respects to the requirements of this contract and the attached specifications; that the designs, materials and workmanship will be the best of their respective kinds as known to the present state of the art; and that the work as a whole, and in every part will be amply strong, durable, complete and operative under all the conditions of operation contemplated by this contract or the attached specifications."

In Section II of the Specification the Contractor acknowledges familiarity with "the Purchaser's system in general", to which the new generators are to be "adapted".

Section III of the Specification, General Requirements, is particularly worthy of note, reading as follows:- "On account of the large amount of power

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dependent on each generator, the magnitude of the plant and system of which it will become a part, the importance of the public service and munition industries served and the critical situation as to the power supply in Ontario, resulting from the existing state of war, it is required that this generator (these generators) shall be designed and built for the highest class of service and completed and installed in the shortest possible time."

In regard to the strength and suitability of materials there is a general section in the Specification, being "Section XXI - Tests of Materials", and reading as follows:- "Samples of those materials proposed to be used in the construction of the generator (generators), whose character will materially affect the security or performance of the same, will be obtained at the time such materials are made and subjected to such mechanical, electrical and other tests as may be necessary to determine the suitability of the materials for use in the generator (generators). Certified reports of all such tests will be furnished to the Purchaser for his information, and no materials shall be used in the generator (generators) which are shown by such tests to be unsuitable for such use. All such tests shall be at the Contractor's expense".

The turbines were manufactured by the S. Morgan Smith Co., of York, Pennsylvania, and it is understood that they were originally intended for the use of a French Aluminum Corporation, later becoming the property of The Aluminum Company of America. Owing to a change in the proposed plan of development, The Aluminum Company finally decided not to use the turbines, and by mutual arrangement they were accepted for use in the new addition of the plant of The Ontario Power Company of Niagara Falls. The arrangement was concluded in

April, 1918, and the turbines were erected during the early part of the year 1919.

The generators were manufactured by the Canadian General Electric Company, Peterborough, Ontario, on a special order for the work under date of January 12th, 1918, and were erected during the first half of the year 1919. The drawing entitled "General Drawings of Generator 15", being page 8 hereof, shows the side elevation, the end elevation, and the top plan of the machine drawn to scale; while the drawing entitled "Details of Rotor Rings of Generator 15", being page 9 hereof, shows the side elevation of the steel cast rotor rings with the field coils in place, an enlarged view of the dove-tails and key slots showing the method of attaching the field coils to the rotor rings, an enlarged sectional view of the steel cast rotor rings with the interlocking details, and the assembly of the steel cast rotor rings on the cast iron spider.

The governors were manufactured by The Lombard Governor Co., Ashland, Massachusetts, and the remainder of the machinery for the addition was supplied by standard makers.

For the operation of these two units the Hydro-Electric Power Commission provided for an additional conduit, No. 3, of wood-stave construction, to convey the water from the intake works to the plant. This conduit, with its own surge tank and penstocks, provided a supply of water for the new addition independently of the older portion of the plant. Otherwise, all the conditions were similar to those obtaining in the older portion.

The total cost of the addition together with Units Nos. 15 and 16 and the auxiliary plant, and the conduit, surge tanks, and penstocks was \$3,514,686.62.

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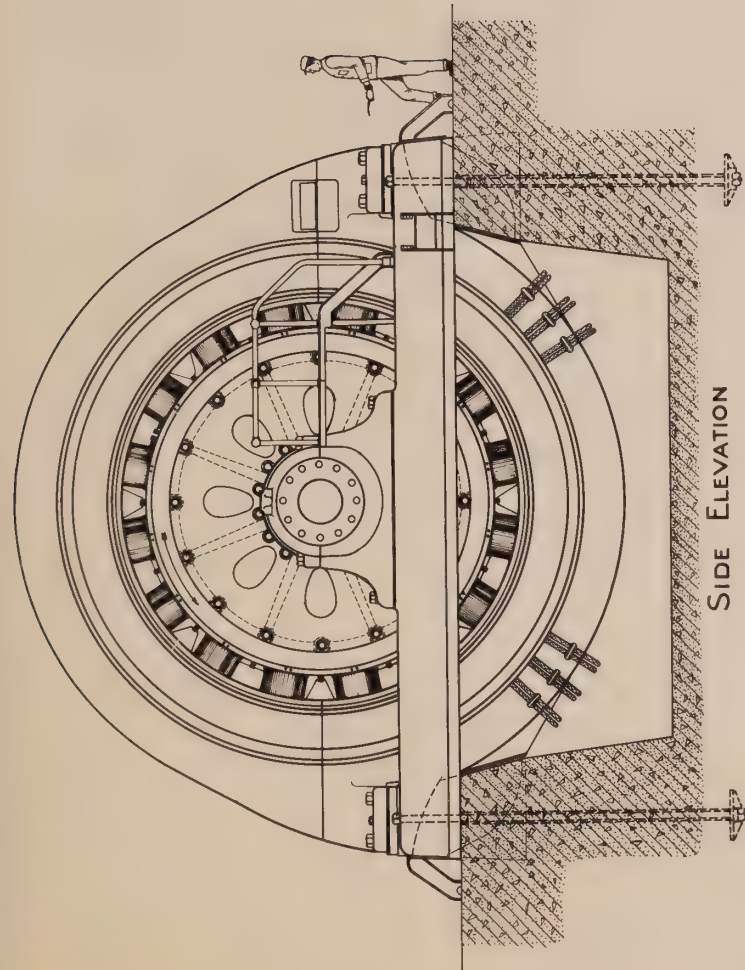
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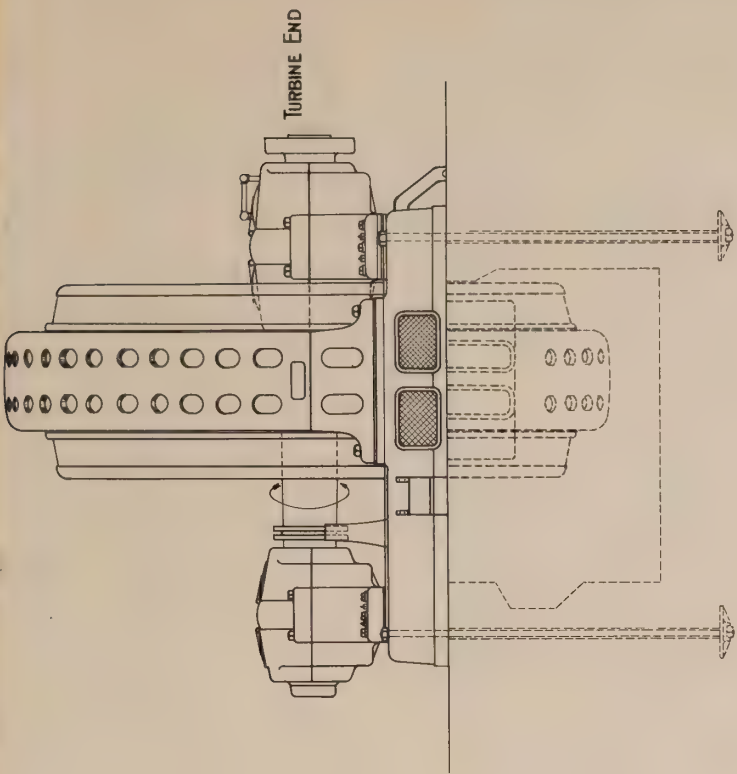
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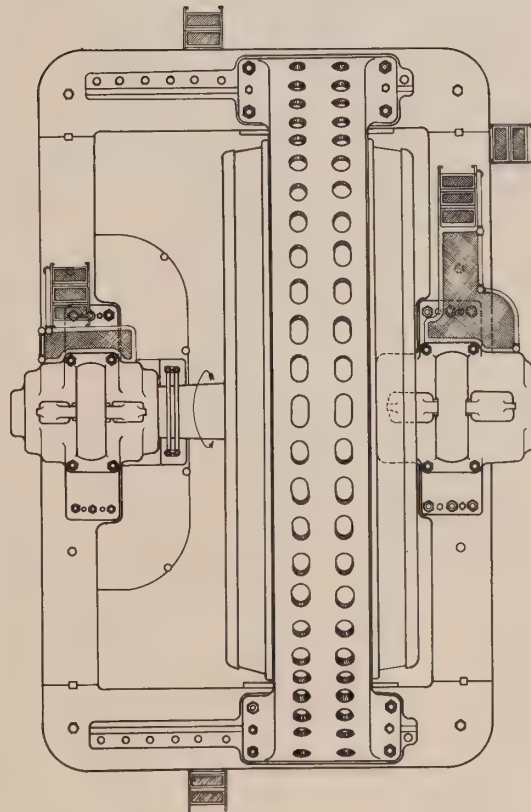
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SIDE ELEVATION



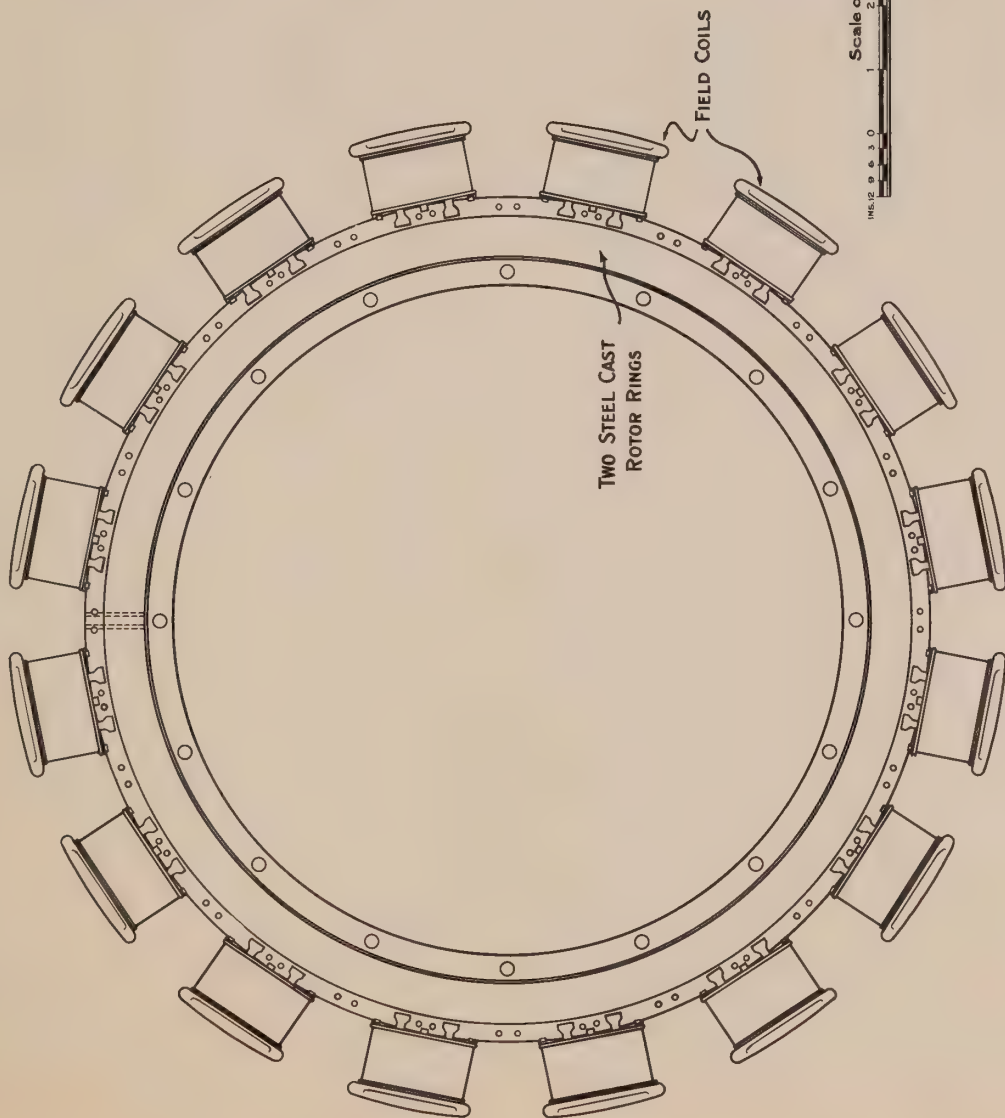
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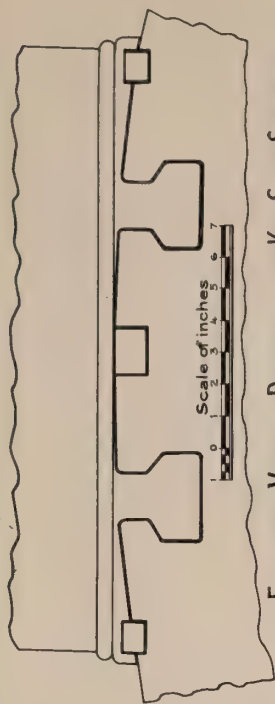
TOP PLAN

Sheet 2

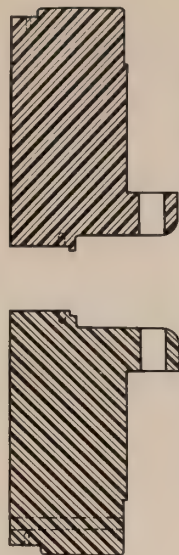
HYDRO-ELECTRIC INQUIRY COMMISSION
W. D. GREGORY - CHAIRMAN
THE ONTARIO POWER COMPANY OF NIAGARA FALLS
**GENERAL DRAWINGS
OF GENERATOR 15**
Toronto, Nov. 18TH 1922. Made by W.H.A. Checked by *W.H.A.*
WALTER J. FRANCIS, C.E.,
CONSULTING ENGINEER



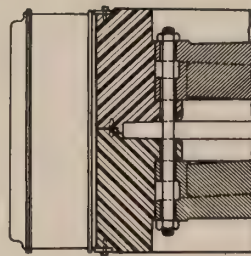
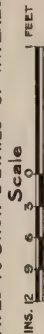
SIDE ELEVATION OF ROTOR RINGS
WITH FIELD COILS IN PLACE



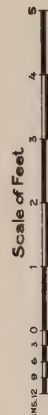
ENLARGED VIEW OF DOVETAILS AND KEY SLOTS SHOWING
METHOD OF ATTACHING FIELD COILS TO ROTOR RINGS



ENLARGED SECTION VIEW OF ROTOR RINGS, RINGS
SEPARATED TO SHOW DETAILS OF INTERLOCKING



ASSEMBLY OF ROTOR RINGS
ON CAST-IRON SPIDER



Sheet 3

HYDRO-ELECTRIC INQUIRY COMMISSION

W. D. GREGORY - CHAIRMAN

THE ONTARIO POWER COMPANY OF NIAGARA FALLS

DETAILS OF ROTOR RINGS OF GENERATOR 15

Toronto, Nov. 18th 1922, Made by W.D.G., Checked by W.D.G.

WALTER J. FRANCIS, C.E.,
CONSULTING ENGINEER

The contract price of the two generators complete and ready for service was \$350,000.00.

The new units were put into service in 1919, No. 15 commencing on June 23rd, and No. 16 on August 12th, and they continued to operate satisfactorily until the moment of the accident on the morning of April 20th, 1922.

Mr. E. T. J. Brandon, the Engineer in charge of the Electrical Department of the Hydro-Electric Power Commission, states in his report later referred to that no official overspeed test was made "on account of load conditions". I am informed by Mr. Gaby that apart from this all the rest of the work proceeded in the regular way. The General Manager of the Canadian General Electric Company has made a similar statement to me.

The Accident.

The Sequence of Events.

While the plant of The Ontario Power Company of Niagara Falls was rendering its usual normal service, in conjunction with the plant of The Canadian Niagara Power Company, in supplying energy to the same transmission lines, the records of the Operating Department show that at 2:44 o'clock in the morning of April 20th, 1922, a short circuit occurred on the 110,000-volt system. Regular steps were taken immediately by the operators of the two plants to guard against further trouble, and the records show that many things were happening within a very short space of time. It is not surprising that Mr. Philp should report to his superiors that the exact sequence of the above

events cannot be determined precisely. I should say that he is in a better position than anyone else to interpret the sequence. Seeing that there appear to be uncertainties in the matter of the electrical events, and being satisfied in my own mind that the failure was of a mechanical nature and not electrical, I shall not discuss the operating records further than to say they appear to be quite in order, the only difficulty arising from the fact that the sequence of so many events in such a brief interval is not clear.

Generator No. 15 is reported to have been operating satisfactorily, apparently, immediately after the short circuit occurred at 2:44 a.m., by the operator-in-charge who went down and looked over the equipment and found everything in proper order. He noted at this time that the gate of Unit No. 16 was wide open, but he does not remember noting the gate opening of Unit No. 15. If Unit No. 15 had a full gate at this time it is unlikely that it would be running at an unusually high speed because it would be accelerating generators Nos. 11 and 12 and The Canadian Niagara Power Company machines.

After the accident the records show that governors Nos. 11 and 12 were functioning correctly. The operators on The Canadian Niagara Power Company plant record a reduction to normal speed in their plant in the ordinary time, and it seems clear that Unit No. 15 must have been running away carrying generators Nos. 11 and 12 with it. The power house operator on duty at Units Nos. 15 and 16 states that generator No. 15 was running much faster than he had ever known it to do before, and that the gates were swinging on a range from 40% to 100% of full opening. He further noticed that the speed was increasing until generator No. 15 went to pieces.

The operator on generators Nos. 15 and 16 reported that a second short circuit came in. This incident, whatever it was, was probably on the instant that The Canadian Niagara Power Company cut out their generator fields.

The governor of Unit No. 15 was apparently not in proper order during the period of the accident, and the condition of the governor head after the accident indicates that the tension spring which opposes the fly-ball motion had been released just about the time of the trouble. The breaking of this spring, however, would permit the fly-balls to take the widest possible position of travel and so act to close the turbine gates, but the general effect might be considered as unstable. **COPY** If the spring had been broken prior to the first short circuit at 2:44 a.m., the governor would probably have held the machine at zero gate with a certain amount of surging, but the graphic watt meter chart does not indicate such a condition. The records show that governor No. 15 had been carefully inspected a fortnight before the accident, and that the lock nuts in the head had been tightened at that time. Regardless of the cause, there is no doubt that generator No. 15 ran away and reached a high speed of revolution which resulted in its complete destruction and a long sequence of damage.

The Damage.

The resulting damage was very great. In addition to reducing itself to debris, the generator of Unit No. 15 set up a train of damage to other units and to that part of the building in which it was housed. A portion of the

The first part of the report is a general description of the project. It is followed by a detailed description of the methodology used. The results of the study are then presented, followed by a discussion of the findings. The report concludes with a summary of the main points and a list of references.

The second part of the report is a detailed description of the methodology used. It includes a description of the data collection methods, the statistical analysis techniques used, and the results of the analysis. This section is followed by a discussion of the findings and a summary of the main points.

The third part of the report is a detailed description of the findings. It includes a description of the data collection methods, the statistical analysis techniques used, and the results of the analysis. This section is followed by a discussion of the findings and a summary of the main points.

rotor weighing approximately ten tons was hurled through the reinforced concrete roof slab of the building. Continuing its path, in its descent it again pierced through the roof slab and finally struck the frame of generator No. 11 where it came to rest. Other fragments of generator No. 15 were thrown upon generator No. 16 with such violence that it was very seriously damaged thereby. Metal of all kinds was reduced to fragments. In the pit of generator No. 15 were afterwards found scores of broken pieces of cast iron the size of paving blocks. The reinforced concrete roof of the room, with its trusses, fell in upon the machinery. The collapse of the roof resulted in the fracturing of the cast iron wheel case of the turbine of Unit No. 15 from which an elliptical shaped portion about eight feet long and about six feet wide was forced, permitting the water in the penstocks from a height of about 120 feet to rush in an uncontrolled torrent into the building, whence it passed to other portions of the plant by way of the doorways and other openings. Some of the water rose above the roof in such volume as to scour the natural face of the exposed cliff at the rear of the power house. The pits of generators Nos. 11, 12, 13 and 14 were filled with water, but, as these machines had already been taken off the line and the fields opened, they did not suffer any damage except by water. Efforts were immediately directed to closing the valve of No. 15 Unit by the valve chamber man with the assistance of operators from the power house. The records show that the valve on No. 15 Unit was closed in the space of four minutes, being the first to be shut, and that all the other valves of Units Nos. 11 to 16, inclusive, were shut within a space of fifteen minutes.

I believe that every important incident during the wrecking is traceable

in proper sequence, but as no useful purpose would be served I shall make no further reference to the matter beyond saying that I have followed it carefully to a conclusion which satisfies me.

The generator of Unit No. 15 was totally destroyed, and the generator of Unit No. 16 was very seriously damaged. One of the wheel cases of the turbine of Unit No. 15 is badly broken and a new casting will be required for it. The fan motors, sump motors and starters for all units from Unit No. 10 up to Unit No. 16 were submerged and suffered water damage. The air compressor took in water, and, while not seriously damaged, the piston rods were bent and the piston rings were broken. The collector rings on generator No. 14 were ruined by the impact of flying debris. Generators Nos. 11, 12, 13 and 14 suffered serious water damage and a period of about two months was required to fit them for return to service. Generator No. 11 received a severe blow on the base frame about four feet from the outside of the stator when it was struck by the heavy piece of debris which came through the roof above, but apart from a deep scar it fortunately sustained no other injury therefrom. The substructure of the addition in which Units Nos. 15 and 16 were installed did not suffer any damage excepting deep surface abrasions. The reinforced concrete galleries of the superstructure of the addition were badly shattered in many places, and the windows were broken. The roof, with its trusses, was completely wrecked.

The operator in the room at the time received a severe shock and minor injuries, more or less directly attributable to the flood, but he was able to return to duty within a few days.

The three photographs included herewith as pages 16 to 18, inclusive,

are intended to illustrate the conditions as soon as the place was unwatered after the accident.

Investigations into the Accident.

All the interested persons immediately began an investigation into the cause of the accident, and personal examinations to that end were made by Mr. Gaby, with all the principal members of his staff, as well as by representatives of the Canadian General Electric Company, builders of the generators of Units Nos. 15 and 16, and the S. Morgan Smith Company, builders of the turbines of Units Nos. 15 and 16. **COPY**

On April 27th, 1922, Mr. Philp made a comprehensive preliminary report to his superior, Mr. Don Carlos.

On July 17th, 1922, Mr. E. F. J. Brandon submitted an extended report to Mr. Gaby, setting forth the details of the accident and including two reports from one of his assistants, Mr. R. E. Stevenson. In Mr. Brandon's report, reference is made to certain studies conducted by Professor Robert W. Angus, M.E.I.C., of the Department of Mechanical Engineering of the University of Toronto, who by request had made an examination of the ruins and subsequently submitted a number of calculations in regard to the steel cast rings of the rotor of generator No. 15.

On July 20th, 1922, Mr. R. B. Young, Assistant Laboratory Engineer of the Hydro-Electric Power Commission, made an extended report through Mr. Dobson

THE SECRETARY OF DEFENSE, WASHINGTON, D.C. 20301
ATTENTION: THE SECRETARY

MEMORANDUM FOR THE SECRETARY

1. The Department of Defense has received information from the
intelligence community that the Soviet Union is currently
conducting a large-scale military exercise in the
Mediterranean region. This exercise is believed to be
a demonstration of the Soviet Union's military capabilities
and its ability to project power into the Middle East.
The exercise is expected to last for several weeks and
will involve a large number of troops and heavy weapons.

COPY

2. The Department of Defense is currently reviewing the
information received and is working to determine the
exact nature and scope of the exercise.

3. The Department of Defense is also working to determine
the impact of the exercise on the stability of the
Middle East region.

4. The Department of Defense is currently working to
determine the exact nature and scope of the exercise.

5. The Department of Defense is currently working to
determine the impact of the exercise on the stability of
the Middle East region. The Department of Defense is
also working to determine the exact nature and scope of
the exercise.

6. The Department of Defense is currently working to
determine the impact of the exercise on the stability of
the Middle East region. The Department of Defense is
also working to determine the exact nature and scope of
the exercise.

COPY

WALTER J. FRANCIS & COMPANY.

COPY FOR ENCLOSURE TO Mr. J. Allan Ross.

To face page 16.

Photograph showing

COPY

General View of H.E.F.C. Addition after the Accident

looking down on Power House from above.

Taken April 20th, 1922.



WALTER J. FRANCIS & COMPANY.

COPY FOR ENCLOSURE TO Mr. J. Allan Ross.

To face page 17.

Photograph showing

COPY

General View of Wreckage of Generator No. 15

looking from above.

Taken May 15th, 1922.



WALTER J. FRANCIS & COMPANY.

COPY FOR ENCLOSURE TO Mr. J. Allan Ross.
To face page 18.

Photograph showing

COPY

Detail View of Wreckage of Generator No. 18.

Taken May 21st, 1922.



to Mr. Brandon regarding the quality of the steel in the broken pieces of the rotor rings. Mr. Young's report covered the tests on standard specimens made from coupons cut out of the fragments, and in the course of his studies he shows that he tried the effect of heat treatment on the steel in the laboratory.

I visited the scene of the accident at the beginning of May, and I have been in the plant so frequently, and in such close touch with the situation ever since, that it is unnecessary to recount the dates. On the occasion of my first visit, I felt so convinced that the cause of the accident was to be found in the quality of the steel in the two rotor rings of generator No. 15 that I believed it justifiable to have all efforts directed towards studying them before making a great expenditure of time or money in any other direction. Mr. Philp and Mr. Gaby concurred in this view.

After consultations with them and with Mr. Dobson we agreed that it would be advantageous to have for consideration the results of commercially annealing the pieces of the steel cast rings. Accordingly, I concluded arrangements with the Penn Seaboard Steel Corporation, Philadelphia, Pennsylvania, to do the desired annealing. This firm is well known, and one with which I have had eminently satisfactory relations for over twenty years. All their equipment is good, and their facilities for commercial annealing are in keeping with the rest of their plant. A fragment of the generator rings similar to that which was hurled from the rotor through the roof, but more convenient for handling being smaller in size, appearing to be generally characteristic, was chosen for the study in annealing. It consisted essentially of almost equal portions of each of the two steel cast rotor rings about three feet in length. The

pieces were cut into half transversely of the rotor, that is squarely across each ring, giving two pieces of each ring about eighteen inches long. One part of each ring was subsequently cut into blanks six inches long from which coupons and test pieces were eventually made, so that all of these blanks were in the natural condition of the steel before the accident. The other two pieces about eighteen inches long were forwarded to the Penn Seaboard Steel Corporation with instructions to anneal them commercially in such a way as to bring out the best quality of the steel. They were duly treated and were returned to Niagara Falls, Ontario, on September 28th, 1922. Subsequently they were cut up into blanks and coupons in exactly the same manner as the unannealed portions. **COPY** All the pieces were numbered systematically throughout, so that the value of every test piece might be compared with that of every other test piece with due regard to its original position in the body of the ring. The drawing included herewith as page 21, entitled "Location of Test Specimens in Rotor Rings", shows how the blanks and coupons were cut out, thirty-two in all. Drawing No. 5, page 26, shows the location of the fragments from which the specimens were cut.

The Cause of the Accident.

General.

The generators in Units Nos. 15 and 16, as already pointed out, had been in satisfactory service for almost three years prior to the time of the accident. It is not recorded that they ever before passed through a crisis such as the

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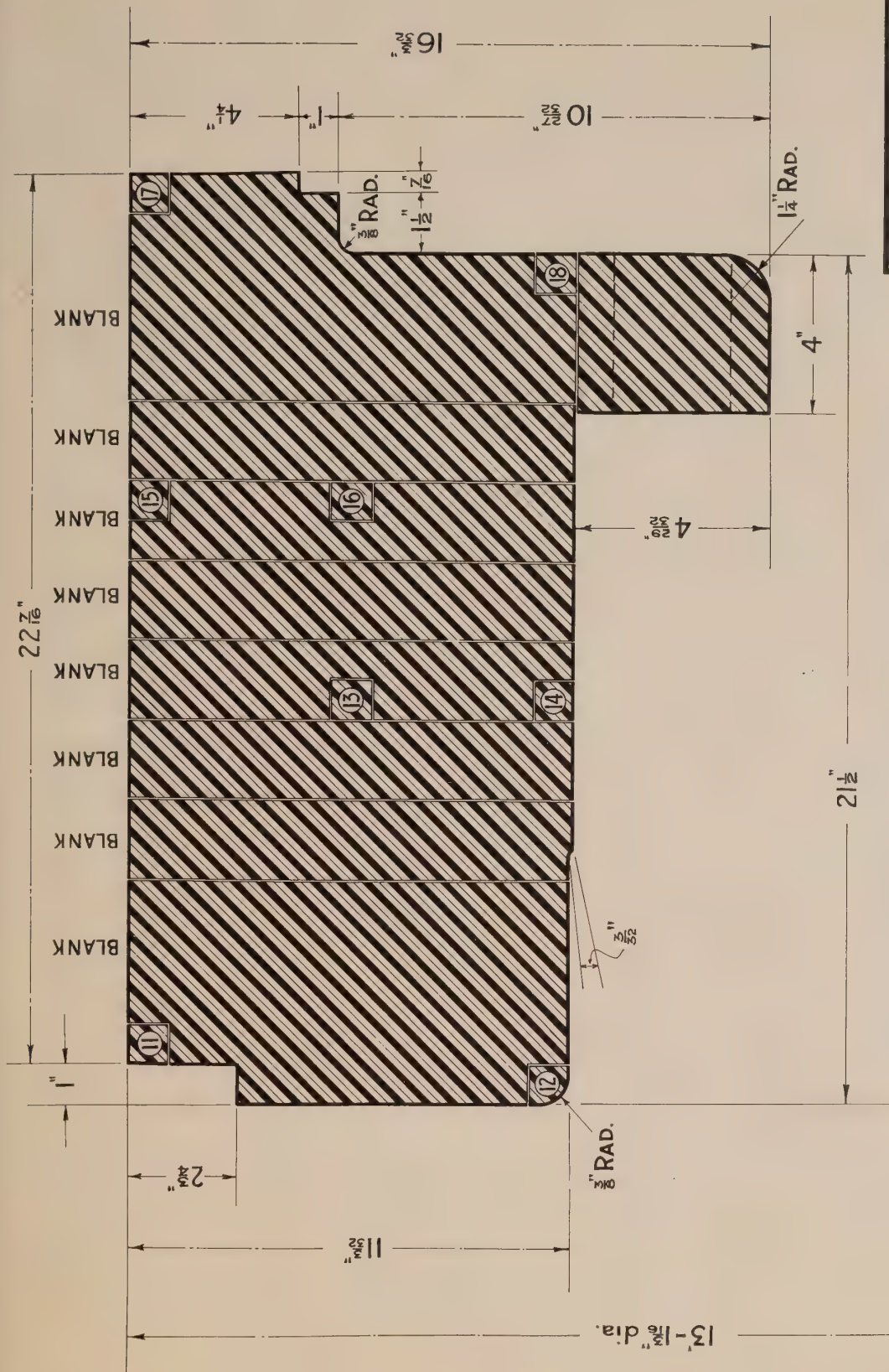
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Sheet 4

CROSS SECTION OF STEEL CAST ROTOR RING

Notes - Each ring was cut squarely across in two places so as to give a piece of ring 6" inches long. This piece was then cut into blanks as shown above. From the blanks were cut coupons one inch square, and from the coupons the standard test specimens were turned. The axis of every test specimen was tangential to the circumference of the ring at the point of its location.

HYDRO-ELECTRIC INQUIRY COMMISSION
W. D. GREGORY - CHAIRMAN
THE ONTARIO POWER COMPANY OF NIAGARA FALLS
**LOCATION OF TEST SPECIMENS
IN ROTOR RINGS**
Toronto, Nov. 18TH, 1922, Made by *SW*, Checked by *WJF*.
WALTER J. FRANCIS, C.E.,
CONSULTING ENGINEER

short circuit at 2:44 o'clock on the morning of April 20th, 1922. Such a crisis, however, should not have resulted in the disaster.

The records show that during the period of the accident, as well as before it, the machines were in charge of the regular, duly qualified operating staff of the plant, and that all the customary procedure was being observed. The functions of the machines were the same as they had been called upon to perform regularly.

In studying the sequence of events, it is clear that the initial failure was not in the turbine of Unit No. 15. It could not have been in any other turbine because no other one was broken.

The case of the turbine of Unit No. 15 was broken by impact from above, the mark being plainly visible on the case. The fractured portion of the turbine case shows an excellent quality of cast-iron, re used in making the casting had shifted slightly during the casting process, the variation caused thereby was not sufficient to account for the failure of the turbine case. The operator noticed that generator No. 15 was giving trouble before any water entered the room.

The suggestion that a leakage from turbine No. 15 might have caused trouble in the generator may be dismissed at once, as there is nothing to show that there was an escape of water from the turbine, excepting through the broken case, a secondary incident that resulted from the crash of the falling roof. Moreover, the operator observed trouble with generator No. 15 while turbine No. 15 was still operating although with accelerated speed.

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The evidence shows that the generator of Unit No. 15 was running for five or six minutes after the short circuit at 2:44 a.m., but during the latter part of this period the speed was increasing, and the operator actually saw the generator fly to pieces. The reason for the acceleration of speed has not been fully cleared up. I can find no evidence to indicate that the stator failed first. On the contrary there are many details indicating that the rotor failed first, and that all the other damage followed in sequence.

The speed attained by the rotor was not observed nor can it be determined with exactness. It is certain, however, that the speed of the turbine could not exceed the spouting velocity of the draft tube. The Hydraulic Department of the Hydro-Electric Power Commission calculates that the runaway speed of turbine No. 15 would be 330 revolutions per minute, and Professor Angus puts it at 347 revolutions per minute as a maximum. My calculations lead me to agree with these figures. The specifications called for a generator to safely stand a runaway speed of 360 revolutions per minute. It would therefore appear that turbine No. 15 was unable to drive generator No. 15 up to the specified runaway speed.

Professor Angus has submitted a number of calculations in his report to show the stresses existing in the rotor rings at a speed of 360 revolutions per minute, and he concludes that the average tensile stress in the steel due to the centrifugal force is 7,010 pounds per square inch, and that the average tensile stress due to the field coils or pole pieces is 9,350 pounds per square inch. In regard to the initial tensile stress in the rings due to their being

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shrunk on to the cast iron spider, he says that it would be "less than 28,400 pounds per square inch". He concludes the report with the statement, "The calculations show that good metal should not have failed at the speed the machine attained".

In the matter of the calculations, I am in agreement with Professor Angus. The principal difficulty lies in determining the conditions that obtained at the moment before the failure. The stresses set up by the revolutions were less than he gives, because the machine did not attain a speed of 360 revolutions per minute. The stresses due to the shrinkage, I should place at quite considerably less than 28,400 pounds per square inch, having in mind the relatively large mass of the steel cast rings as compared with that of the cast iron spider, and the sometimes forgotten fact that cast iron has no elastic limit in compression. The Chief Engineer of the Canadian General Electric Company has told me that the Company's record of the shrinkage operations show that the cast iron spider was reduced in size by the cooling of the steel cast rings, as I should have expected, but the record does not give the exact change in the outside diameter of the spider. The drawings called for the inner diameter of the rings to be one-eighth of one inch less than the corresponding outside diameter of the spider, and it is on the assumption that the cast iron spider did not shrink in the process that Professor Angus bases his computations. Having regard to all the circumstances my own view is that the stresses set up as a result of the shrinkage were something on the order of 16,000 or 17,000 pounds per square inch. These discussions would appear to add weight to the view of Professor Angus in regard to the

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strength of the steel cast rings.

The Study of the Steel Cast Rotor Rings.

After the building debris had been separated from the wreckage of the machinery, the fragments of the two steel cast rotor rings of generator No. 15 were assembled in order on the floor of the room, and finally checked over to confirm their positions. The drawing included herewith as page 26, entitled "Details of Rotor Rings of Generator No. 15 after the Accident", shows in elevation view the actual position of the fractures in both rings, while the photograph included herewith as page 27 shows the assembly of the fragments lying in a circle on the floor.

The fractures of the rings show a very considerable variation in the quality of the steel, evidenced to the practised eye by the crystalline structure which varies generally from a fine grain near the outer walls of the castings to an exceedingly coarse grain towards the heart of the castings. Moreover, the fractures vary among themselves, and altogether show an utter lack of homogeneity.

The General Manager of the Canadian General Electric Company has informed me that all the usual tests and the inspection at the foundry were done for them by the Canadian Inspection and Testing Company, probably the oldest institution of its kind in point of long establishment in Canada, and that everything was satisfactorily reported. He further states that it is his information that

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THE UNIVERSITY OF CHICAGO
PRESS
CHICAGO, ILL. 60637



WALTER J. FRANCIS & COMPANY.

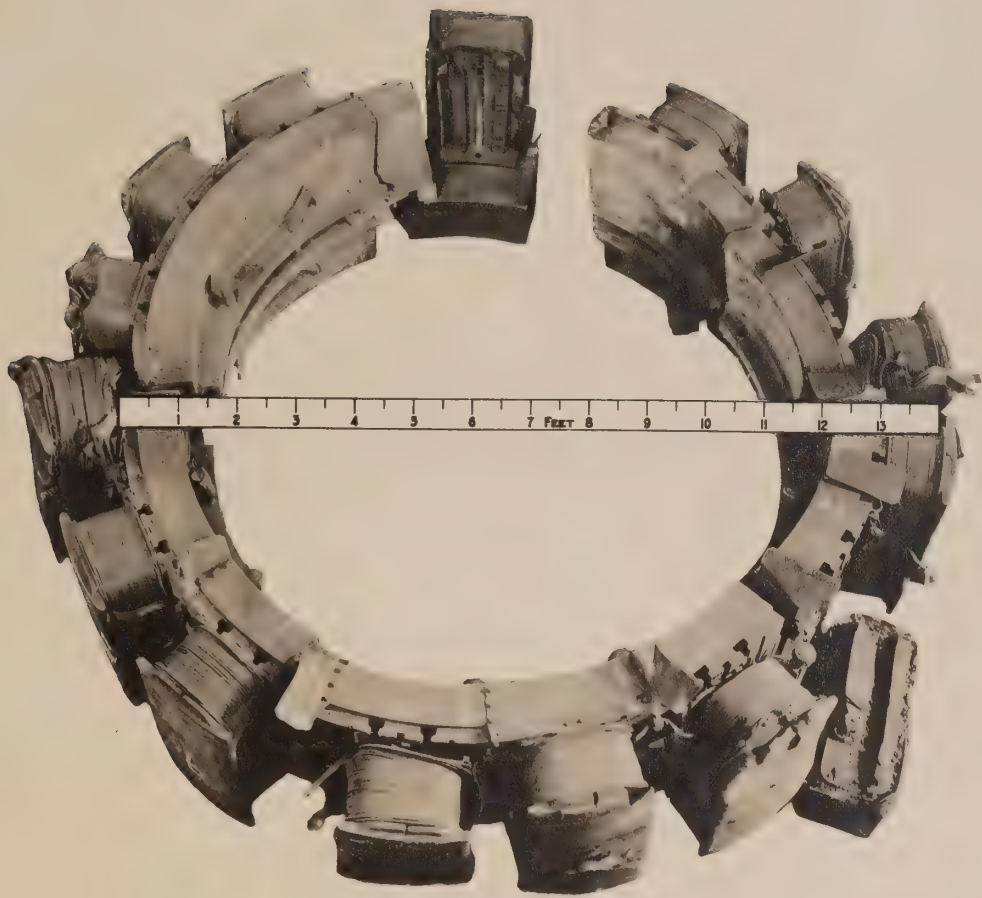
COPY FOR ENCLOSURE TO Mr. J. Allan Ross.

To face page 27.

Photograph showing

Assembly of Fragments of Motor Links on Power House Floor.

Taken November 15th, 1922.



the rings of the two rotors were considered four of the best steel castings that ever entered their shops, and that the machining done in finishing them showed metal of excellent and uniform quality. This statement is not inconsistent with the facts as revealed in the wreckage, when one considers that the only machining done in the Contractor's shops was on the outer surfaces only, where such annealing as the castings originally received would have the most beneficial effect, and that no machining nor cutting was required in the heart of the castings where the effect of the annealing would be the least.

In preparing the coupons and blanks decided upon for the thirty-two specimens, great difficulty was experienced with the drills and cutting tools owing to the hardness and the wide variation in the quality of the metal of the fragments as taken from the wreckage, whereas the corresponding coupons and blanks from the same fragment of metal after annealing gave no trouble whatever in the cutting. It will be noted that the coupons and blanks embraced the whole cross-sectional area of the rings.

The heat treatment given to the annealed fragments consisted of treating the castings at 1640° Fahrenheit for nine hours, cooling quickly to black, and reheating to 1520° Fahrenheit for nine hours, and cooling slowly.

Each of the rings in the rotor weighed 31,400 pounds finished, being equivalent to about 45,000 pounds as a rough casting. This would probably involve the handling of over fifty tons of molten steel in the foundry for

the pouring of a ring.

Results of Tests on Specimens Cut from the Rotor Rings.

The tests on the thirty-two tensile test specimens were concluded on November 9th, 1922. All the specimens were made in accordance with the standards of the American Society for Testing Materials. The specimens were tested to destruction in a standard Olsen testing machine, and the manner of mounting the specimens in the machine with self-aligning holders of the ball and socket type may be clearly seen by reference to the photograph included herewith as page 30. The strain gauge attached to the specimen enabled the yield point to be very accurately determined.

All the tests were carried out by Mr. Young under the general direction of Mr. Dobson.

For the sake of brevity, instead of saying fragment 11 from ring No. 1, or fragment 12 from ring No. 2, or some such nomenclature, I have used the simple expression "ring No. 11" or "ring No. 12" as referring thereto. This brief form has been carried through all the text, drawings and photographs.

Drawing No. 5, included herewith as page 26, together with the photograph of the assembly of the fragments of the rotor rings included herewith as page 27, show clearly the portion of the rings from which the test specimens were taken, the drawing also indicating the part of the fragments chosen for annealing.



WALTER J. FRANCIS & COMPANY

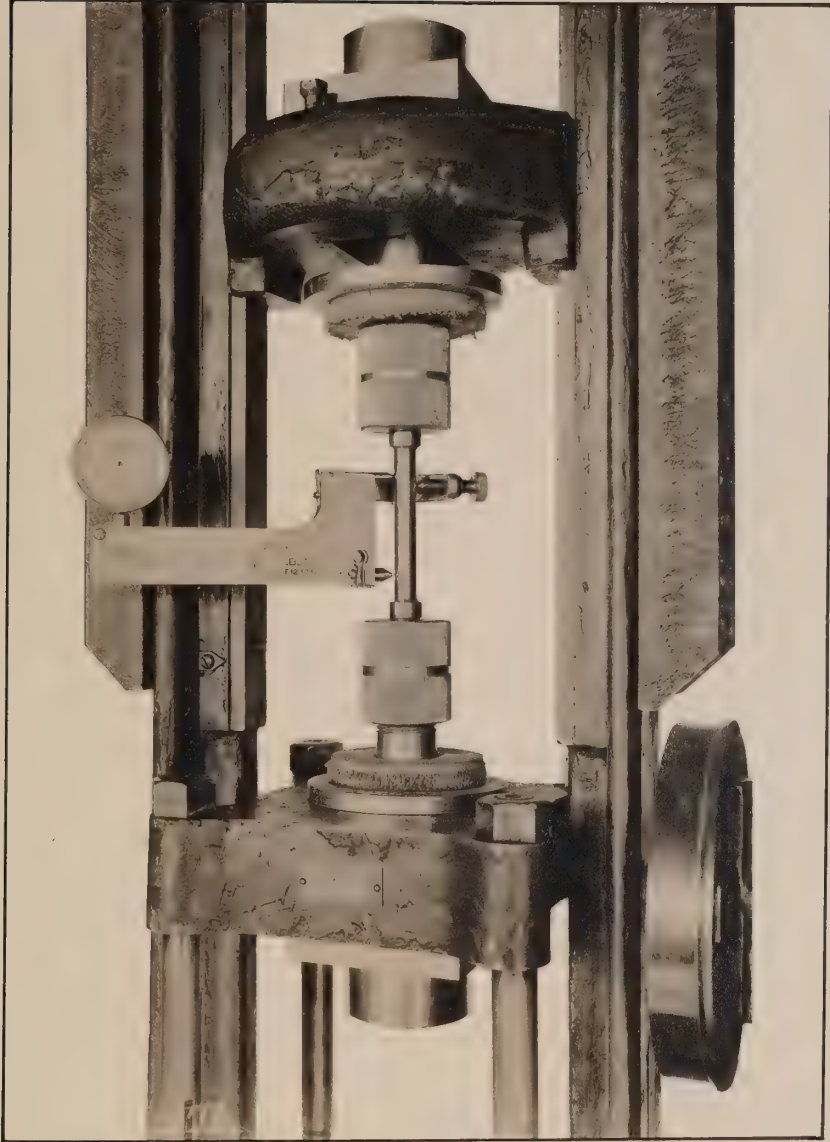
Mr. J. Allan Ross.
To face page 30.

Photograph showing

COPY

Method of Mounting Specimen in Testing Machine

Taken November 4th, 1922.



The following are the results of the tests on the eight specimens of ring No. 11, as cut from the fragment without heat treatment:-

Specimen No.	Elas. Lt. pds. per sq. in.	Ult. Str. pds. per sq. in.	% Elong. in 2 ins.	% Reduc- tion in Area	Remarks
11	29,880	62,250	20.0	19.8	Fracture, square, coarse and crystalline.
12	28,100	63,000	23.0	38.8	Fracture, semi-cup, mixed coarse crystals and granular.
13	29,000	64,400	20.5	19.0	Fracture, square cup, coarse crystalline.
14	28,800	64,800	14.0	11.4	Fracture, square, coarse crystalline.
15	28,450	66,000	15.5	17.4	Fracture, square, coarse crystalline.
16	27,550	62,200	11.0	13.9	Fracture, square, coarse crystalline. Failed outside of punch marks.
17	29,100	61,500	5.0	4.8	Fracture, square, coarse crystalline. Failed outside of punch marks.
18	29,200	60,150	5.0	3.6	Fracture, square, coarse crystalline.

The average of the above series of eight tests is as follows:-

28,560 63,050 14.25 16.00

On September 1, 1994, the following information was received from the [redacted] regarding the [redacted] and the [redacted] (see page 10 of 10).

Account	1994	1995	1996	1997	1998
1. [redacted]	100	100	100	100	100
2. [redacted]	100	100	100	100	100
3. [redacted]	100	100	100	100	100
4. [redacted]	100	100	100	100	100
5. [redacted]	100	100	100	100	100
6. [redacted]	100	100	100	100	100
7. [redacted]	100	100	100	100	100
8. [redacted]	100	100	100	100	100
9. [redacted]	100	100	100	100	100
10. [redacted]	100	100	100	100	100
11. [redacted]	100	100	100	100	100
12. [redacted]	100	100	100	100	100
13. [redacted]	100	100	100	100	100
14. [redacted]	100	100	100	100	100
15. [redacted]	100	100	100	100	100
16. [redacted]	100	100	100	100	100
17. [redacted]	100	100	100	100	100
18. [redacted]	100	100	100	100	100
19. [redacted]	100	100	100	100	100
20. [redacted]	100	100	100	100	100
21. [redacted]	100	100	100	100	100
22. [redacted]	100	100	100	100	100
23. [redacted]	100	100	100	100	100
24. [redacted]	100	100	100	100	100
25. [redacted]	100	100	100	100	100
26. [redacted]	100	100	100	100	100
27. [redacted]	100	100	100	100	100
28. [redacted]	100	100	100	100	100
29. [redacted]	100	100	100	100	100
30. [redacted]	100	100	100	100	100
31. [redacted]	100	100	100	100	100
32. [redacted]	100	100	100	100	100
33. [redacted]	100	100	100	100	100
34. [redacted]	100	100	100	100	100
35. [redacted]	100	100	100	100	100
36. [redacted]	100	100	100	100	100
37. [redacted]	100	100	100	100	100
38. [redacted]	100	100	100	100	100
39. [redacted]	100	100	100	100	100
40. [redacted]	100	100	100	100	100
41. [redacted]	100	100	100	100	100
42. [redacted]	100	100	100	100	100
43. [redacted]	100	100	100	100	100
44. [redacted]	100	100	100	100	100
45. [redacted]	100	100	100	100	100
46. [redacted]	100	100	100	100	100
47. [redacted]	100	100	100	100	100
48. [redacted]	100	100	100	100	100
49. [redacted]	100	100	100	100	100
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52. [redacted]	100	100	100	100	100
53. [redacted]	100	100	100	100	100
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67. [redacted]	100	100	100	100	100
68. [redacted]	100	100	100	100	100
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72. [redacted]	100	100	100	100	100
73. [redacted]	100	100	100	100	100
74. [redacted]	100	100	100	100	100
75. [redacted]	100	100	100	100	100
76. [redacted]	100	100	100	100	100
77. [redacted]	100	100	100	100	100
78. [redacted]	100	100	100	100	100
79. [redacted]	100	100	100	100	100
80. [redacted]	100	100	100	100	100
81. [redacted]	100	100	100	100	100
82. [redacted]	100	100	100	100	100
83. [redacted]	100	100	100	100	100
84. [redacted]	100	100	100	100	100
85. [redacted]	100	100	100	100	100
86. [redacted]	100	100	100	100	100
87. [redacted]	100	100	100	100	100
88. [redacted]	100	100	100	100	100
89. [redacted]	100	100	100	100	100
90. [redacted]	100	100	100	100	100
91. [redacted]	100	100	100	100	100
92. [redacted]	100	100	100	100	100
93. [redacted]	100	100	100	100	100
94. [redacted]	100	100	100	100	100
95. [redacted]	100	100	100	100	100
96. [redacted]	100	100	100	100	100
97. [redacted]	100	100	100	100	100
98. [redacted]	100	100	100	100	100
99. [redacted]	100	100	100	100	100
100. [redacted]	100	100	100	100	100

The balance of the above account as of the end of the period is as follows:

100.00 100.00 100.00 100.00 100.00

The following are the results of the tests on the eight specimens of ring No. 11, as cut from the fragment after annealing. These specimens are exactly comparable with the above eight specimens, number by number, as to location in the body of the casting, and, each by each, they were cut with their ends as nearly adjacent as practicable to the others in the original casting:-

Specimen No.	Elas. Lt. pds. per sq. in.	Ult. Str. pds. per sq. in.	% Elong. in 2 ins.	% Reduc- tion in Area	Remarks
11A	33,600	68,500	32.5	39.5	Fracture, silky half cup.
12A	34,900	70,600	30.5	47.2	Fracture, silky half cup.
13A	34,500	70,600	29.0	33.6	Fracture, silky half cup.
14A	33,100	72,500	19.5	17.5	Fracture, square, one-third silky, two-thirds fine crystalline.
15A	37,700	69,800	7.0	16.9	Fracture, square, fine crystalline.
16A	41,700	65,000	3.0	3.2	Fracture, square, fine crystalline.
17A	51,100	73,500	9.5	10.5	Fracture, square, fine crystalline.
18A	35,450	73,100	13.5	19.0	Fracture, square, fine crystalline.

The average of the above series of eight tests is as follows:-

35,231 70,585 16.2 23.40

The following table shows the details of the transactions recorded in the account during the period. The transactions are classified into four categories: Opening Balance, Deposits, Withdrawals, and Closing Balance. The amounts are shown in the currency of the account.

Category	01/01/2024	01/02/2024	01/03/2024	01/04/2024	01/05/2024
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Opening Balance	100.00	100.00	100.00	100.00	100.00
Deposits	50.00	50.00	50.00	50.00	50.00
Withdrawals	20.00	20.00	20.00	20.00	20.00
Closing Balance	130.00	130.00	130.00	130.00	130.00
Interest	0.00	0.00	0.00	0.00	0.00
Commission	0.00	0.00	0.00	0.00	0.00
Net Change	80.00	80.00	80.00	80.00	80.00
Balance	100.00	180.00	260.00	340.00	420.00
Interest	0.00	0.00	0.00	0.00	0.00
Commission	0.00	0.00	0.00	0.00	0.00
Net Change	0.00	0.00	0.00	0.00	0.00
Balance	100.00	180.00	260.00	340.00	420.00

The total balance at the end of the period is 420.00.

100.00 180.00 260.00 340.00 420.00

In like manner the tests were conducted on the corresponding specimens from ring No. 12. The results are given for the untreated specimens in the next succeeding table, and are directly parallel with the first table of results for ring No. 11.

Specimen No.	Klas. Lt. pds. per sq. in.	Ult. Str. pds. per sq. in.	$\frac{1}{2}$ Elong. in 2 ins.	$\frac{1}{2}$ Reduc- tion in Area	Remarks
11	27,200	64,200	21.5	36.9	Fracture, half cup, coarse crystals, semi-silky. Failed outside of punch mark.
12	19,250	65,100	26.5	42.2	Fracture, half cup, mixture of granular and coarse crystals.
13	28,700	71,900	21.5	21.4	Fracture, half cup, coarse crystals.
14	30,300	69,500	20.0	16.2	Fracture, half cup, coarse crystals.
15	30,250	57,000	3.0	3.0	Fracture, square, very coarse crystalline.
16	34,200	34,700	1.5	0.5	Fracture, square, very coarse crystalline. Flaw in fracture.
17	34,200	58,400	2.5	1.9	Fracture, square, very coarse crystalline.
18	14,750	61,000	2.5	1.6	Fracture, square, very coarse crystalline. Failed outside of punch marks.

The average of the above series of eight tests is as follows:—

27,550 60,250 12.35 15.45

Similarly the tests on the specimens cut from the annealed fragment of ring No. 12 resulted as follows, and are comparable with the three former tables in due order.

Specimen No.	Elas. Lt. pds. per sq. in.	Ult. Str. pds. per sq. in.	% Elong. in 2 ins.	% Reduc- tion in Area	Remarks
11A	29,850	70,500	28.0	37.1	Fracture, silky half cup with granular spots.
12A	35,800	72,100	32.0	50.0	Fracture, silky half cup.
13A	36,200	78,800	21.0	23.8	Fracture, square, fine crystalline.
14A	27,100	74,150	29.0	31.0	Fracture, half silky, half fine crystalline half cup.
15A	35,450	77,300	5.5	4.5	Fracture, square, fine crystalline. Two flaws in fracture.
16A	34,700	87,800	0.5	6.7	Fracture, square, fine crystalline.
17A	33,700	84,750	11.5	11.9	Fracture, square, fine crystalline.
18A	37,600	82,000	13.0	12.8	Fracture, square, fine crystalline.

The average of the above series of eight tests is as follows:-

35,900 76,450 18.2 22.2

In order to show clearly the details of the broken test specimens, we have made full size photographs of four specimens from ring No. 11, and four from ring No. 12, and included them herewith as page 36 and page 37 respectively. These specimens are 12 and 12A, and 16 and 16A, in both cases, thus giving characteristic side views of corresponding specimens from both rings. They are also typical of the whole thirty-two specimens.

We have also made a photograph, included herewith as page 38, showing the structure at the end fracture of every one of the thirty-two specimens full size. The ends are arranged in order in two rows for each ring, the upper row being from the untreated fragment, and the lower from the annealed fragment. Comparison may also be made ~~directly~~ directly from one ring to the other.

In pursuing his studies, Mr. Young has made some microscopic photographs of the effect of the annealing on the crystalline structure of the steel, and one of the photographs showing a section before and after heat treatment is included herewith as page 39. It shows in most graphic form the change in the crystalline structure resulting from the annealing.

Conclusions drawn from the Study and the Tests.

As already stated the fractured surfaces of the steel cast rotor rings of generator No. 15 bore universal evidence of the fact that the metal was lacking in homogeneity throughout the cross section. In every instance the crystalline structure, always very coarse near the heart of the section, showed a finer texture near the surface of the casting than elsewhere.

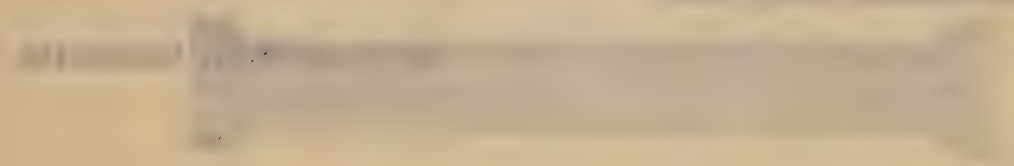


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To face page 36.

Specimen No.12, Unannealed

Specimen No.12-A, Annealed

Photograph showing

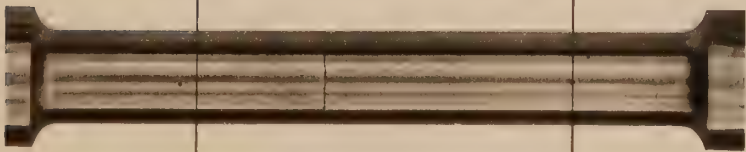
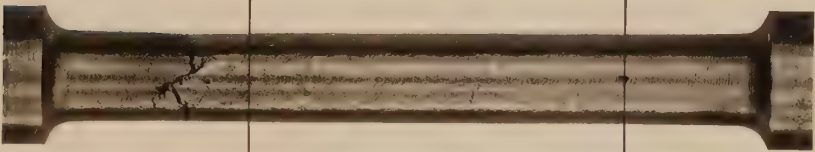
Full Size View of Four Test Specimens
from Rotor Ring No. 11.

Taken November 14th, 1922.

Specimen No.16, Unannealed

Specimen No.16-A, Annealed

Note:- The two black lines are exactly two inches apart and the specimens have been set at zero on the right hand line, so that the elongation may be readily observed by comparing the punch mark with the left hand line.



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To face page 37.

Specimen No.12, Unannealed

Specimen No.12-A, Annealed

Photograph showing

Full Size View of Four Test Specimens

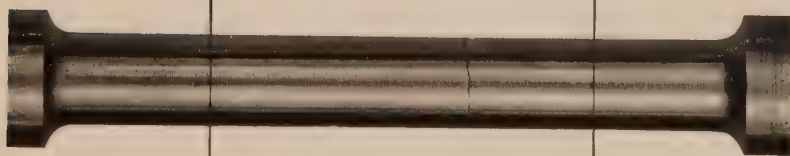
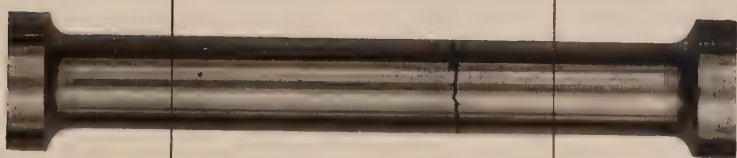
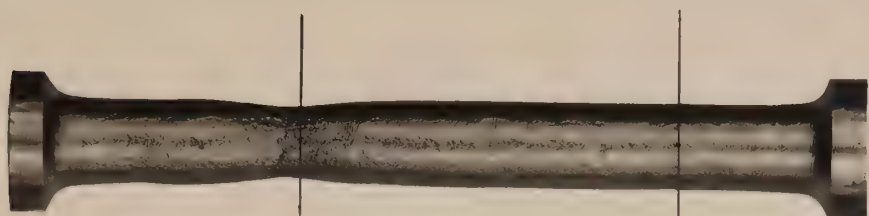
from Motor Ring No. 12.

Taken November 14th, 1922.

Specimen No.16, Unannealed

Specimen No.16-A, Annealed

Note:- The two black lines are exactly two inches apart and the specimens have been set at zero on the right hand line, so that the elongation may be readily observed by comparing the punch mark with the left hand line.



RIND N°12

Handwritten text

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12

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Handwritten text

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RIND N°11

COPY

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To face page 36.

















Photograph showing

















COPY

Full Size View of the End Fractures of the Thirty-two Test Specimens.

Taken November 14th, 1922.

RING №11

Unannealed	11	12	13	14	15	16	17	18	Unannealed
									
Annealed	11A	12A	13A	14A	15A	16A	17A	18A	Annealed
									

Unannealed	11	12	13	14	15	16	17	18	Unannealed
									
Annealed	11A	12A	13A	14A	15A	16A	17A	18A	Annealed
									

RING №12

THE UNIVERSITY OF CHICAGO
LIBRARY
1100 EAST 58TH STREET
CHICAGO, ILL. 60637



UNIVERSITY OF CHICAGO

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LIBRARY
1100 EAST 58TH STREET
CHICAGO, ILL. 60637



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To face page 39.

After Annealing

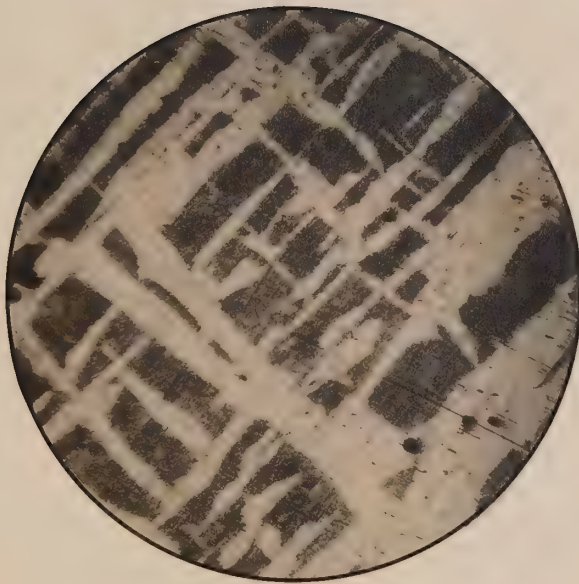
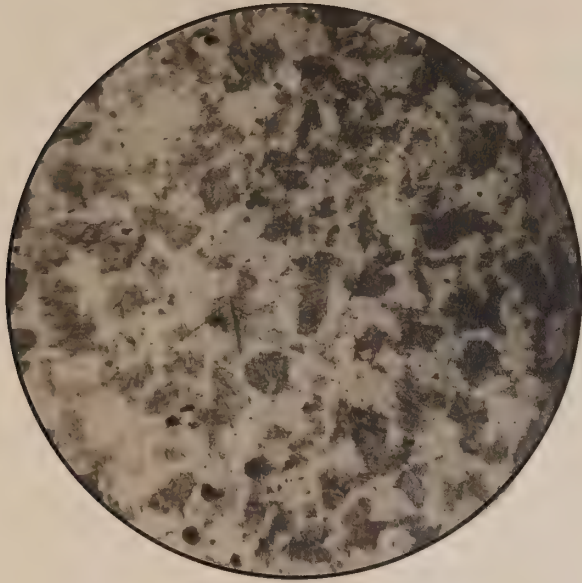
Micro-photographs of Motor Rings

Before and After Annealing.

Magnification. Sixty Diameters.

Taken August 22nd, 1922.

Before Annealing



In view of the fact that the stresses in such an element are always calculated for a uniform distribution over the whole cross sectional area of the element, it will be readily seen that absence of uniformity in the metal may be a serious matter.

The tests on the thirty-two specimens confirm the general finding in every instance, piece by piece and ring by ring, especially in regard to the percentage of elongation and the percentage of reduction in area, the two factors which indicate the ductility of the metal. It will be observed that even these factors vary between very wide limits, not only in the untreated specimens, but also in those cut from the annealed metal. It is doubtless beyond the scope of my instructions to do more than point out a very interesting divergence in the figures regarding reduction in area on the left hand side of the cross section of both of the rings as compared with the right hand on the drawing included herewith as page 41. In every case the ultimate strength and the elastic limit was materially improved by the heat treatment. This drawing is self explanatory, and would appear to indicate a result due to a definite foundry practice regarding the details of which I am unaware. As already stated, each of the rings in the rough weighed over twenty-two tons, and it will be seen that it was necessary to handle a very large amount of molten metal in making the castings.

None of the specimens cut from the untreated metal would pass the standard specifications for steel castings, although I do not doubt the statement of the General Manager of the Canadian General Electric Company that the Testing Laboratory reported favourably. By current practice their tests would be upon

In view of the fact that the evidence in such an element are always

estimated with a certain amount of error, it will be found that the evidence in such an element is always estimated with a certain amount of error.

The tests on the following specimens confirm the general finding in

very few cases, where it is found that the evidence in such an element is always estimated with a certain amount of error, it will be found that the evidence in such an element is always estimated with a certain amount of error.

the divergence in the figures regarding reduction in area on the last part

of the specimen is due to the fact that the evidence in such an element is always estimated with a certain amount of error.

It is found that the evidence in such an element is always estimated with a certain amount of error.

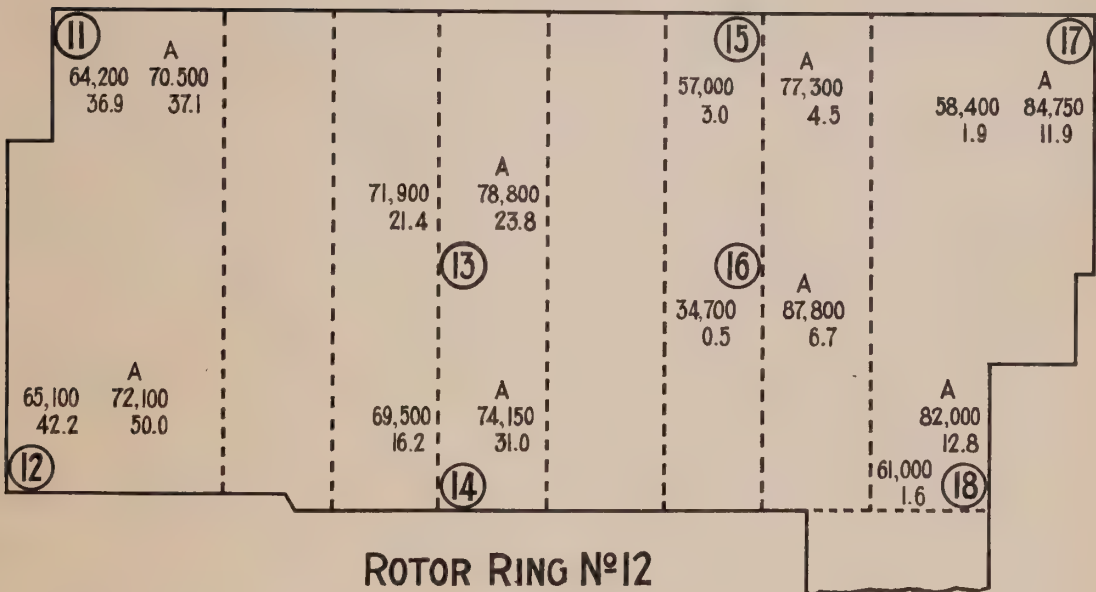
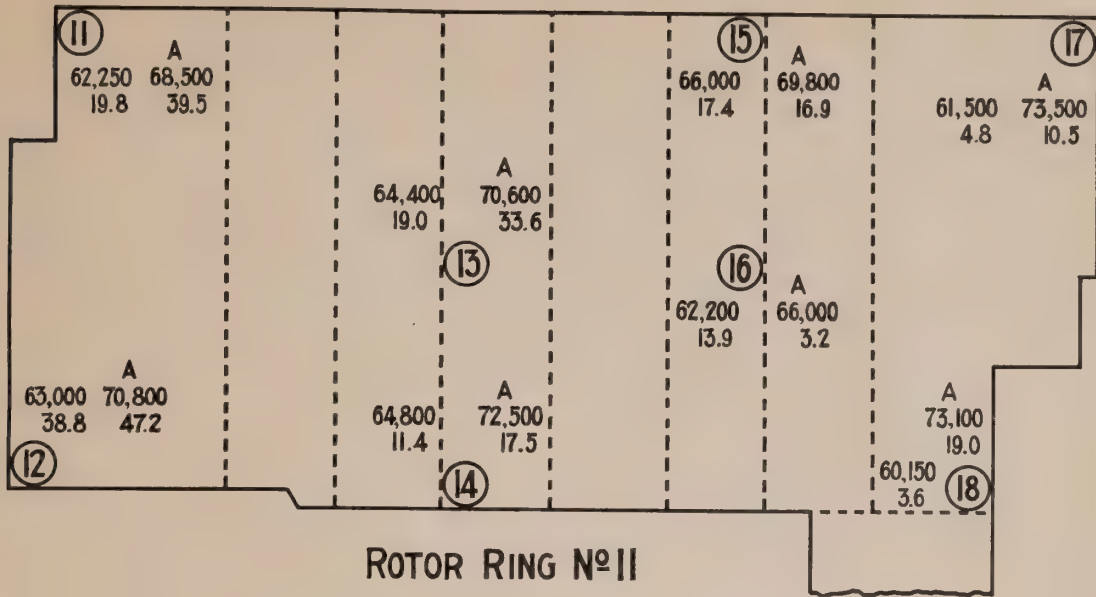
The divergence in the figures regarding reduction in area on the last part

of the specimen is due to the fact that the evidence in such an element is always estimated with a certain amount of error.

It is found that the evidence in such an element is always estimated with a certain amount of error.

The divergence in the figures regarding reduction in area on the last part

of the specimen is due to the fact that the evidence in such an element is always estimated with a certain amount of error.



Sheet 6

NOTE - (16) denotes number and location of test specimens.

The group of figures to the left of the specimen give the ultimate strength and the reduction of area before annealing, while the group to the right of the specimen give the corresponding results after annealing.

HYDRO-ELECTRIC INQUIRY COMMISSION

W. D. GREGORY - CHAIRMAN

THE ONTARIO POWER COMPANY OF NIAGARA FALLS
**DIAGRAM SHOWING RESULTS OF TESTS
 ON THIRTY-TWO TEST SPECIMENS
 FROM ROTOR RINGS OF GENERATOR 15**

Toronto, Nov. 14th, 1922. Made by ~~W. J. Francis~~ Checked by *L. L. J.*

WALTER J. FRANCIS, C.E.,
 CONSULTING ENGINEER

specimens cut from coupons especially left projecting from the body of the casting for the purpose.

But the tests on the thirty-two specimens reveal a still more important fact, namely that the character of the metal is entirely changed by annealing. Practically all of the specimens cut from the annealed metal would pass the standard specifications for steel castings, and the few that do not come up to the exact requirements would not be considered by me as a justification for rejection but rather as a need of further study. These tests prove beyond doubt that the rotor rings would have been rendered practically homogeneous by proper heat treatment. In passing, I would mention two effects of annealing or heat treatment on steel castings,- first, the relief of all internal stresses in the body of the casting, and second, the change in the crystalline structure of the metal. The former is of great importance, because in the untreated condition a steel casting may be so full of internal or initial stresses, working in opposing ways or otherwise,- nobody can say - as to be on the point of fracturing itself. A ring such as those under consideration, however, is one of the most favourable forms of a casting, giving less opportunity for internal stresses than more complex shapes. Hence, the importance of heating the metal of the casting to such a degree of plasticity that these initial stresses are relieved. The latter effect is even more important, inasmuch as it actually changes the character of the metal and produces a ductility comparable to a certain extent with that of rolled steel, whereby the metal is enabled to resist stresses according to the laws of the elastic properties of metals, on which all our theories of stress resistance are based.

I would digress at the moment to express the earnest hope that Mr. Dobson and Mr. Young may be enabled to pursue their investigations in the interest of the art, and especially if there is a possibility of generator No. 16 being reconstructed, for there is nothing to indicate that it is not identical in every structural particular with generator No. 15. I should also note that the studies conducted by Mr. Dobson and Mr. Young in the laboratory prior to the more comprehensive series above referred to, have all pointed to the same general conclusion. For my purpose the studies now finished are conclusive.

General Conclusions and Recommendations.

The Immediate Cause of the Accident.

I am definitely of the opinion that the accident resulted from the failure of the steel cast rotor rings of generator No. 15 while the rotor was revolving at a speed less than that specified as the safe overspeed of the machine. The failure of the rotor rings was in turn due to the inferior quality and the lack of uniformity of the metal of which the rings were composed, as revealed in the wreckage but hitherto unseen in the process of manufacture. The absolute sequence of events during the failure can never be determined, that is to say whether a pole piece of the rotor gave way first due to the tearing action of a wedge, or whether a rotor ring fractured first, but in my judgment the point is not important as in both cases the quality of the metal is immediately involved.

Suggestion for Practice in the Use of Steel Castings in Electrical Machinery.

In considering the broad question of practice in the use of steel castings as important structural elements in the manufacturing of electrical machinery, I believe the recognized professional organizations of engineers should immediately confer with the leading manufacturers of electrical machinery and with the leading steel foundry firms with a view to arriving at a general standard specification which will ensure the use of only such steel castings as are of proven quality and homogeneity. Speaking in the most general way, I am convinced that there is a sincere desire on the part of all to design and manufacture machines of absolute trustworthiness, nevertheless, I know of no standardized attempt to regulate the quality of steel castings.

As a constructive suggestion, I would say that the metal of steel castings used as structural elements of importance in electrical machinery should have the following physical characteristics as a minimum when tested in standard test specimens:- ultimate strength, 70,000 pounds per square inch; elastic limit, 45% of the ultimate strength; elongation in 2 inches, 23%; and reduction of area at point of fracture, 30%. And further, that every steel casting should be subjected to such heat treatment as may be indicated by the chemical composition of the metal to produce complete homogeneity throughout the entire body of the casting, as evidenced by the fulfilment of the above physical requirements, and that the ultimate effect of the heat treatment be proven by the cutting up and examination of one or more specimens of like mass, that is to say, of equal cross section and of a length greater than the least

WALTER J. FRANCIS & COMPANY.

LETTER ENCLOSED TO Mr. J. Allan Ross.

(45)

transverse dimension, treated in identically the same way as the casting itself.

Walter J. Francis

Consulting Engineer.

Toronto, November 18th, 1922.

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